April 2004

Testing the mirror world hypothesis for the close-in extrasolar planets

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Because planets are not expected to be able to form close to stars due to the high temperatures, it has been suggested that the observed close orbiting (~ 0.05 AU) large mass planets ($\sim M_J$) might be mirror worlds – planets composed predominately of mirror matter. The accretion of ordinary matter onto the mirror planet (from e.g. the solar wind from the host star) will make the mirror planet opaque to ordinary radiation with an effective radius R_p. It was argued in a previous paper, astro-ph/0101055, that this radius was potentially large enough to explain the measured size of the first transiting close-in extrasolar planet, HD209458b. Furthermore, astro-ph/0101055, made the rough prediction: $R_p \propto \sqrt{\frac{T_s}{M_p}}$, where T_s is the surface temperature of the ordinary matter in the mirror planet and M_p is the mass of the planet (the latter dependence being the more robust prediction). We compare this prediction with the recently discovered transiting planets, OGLE-TR-56b and OGLE-TR-113b.

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Since the 1995 discovery of a planet around the star 51 Pegasi[1], more than 100 extrasolar planets have been found[2]. Perhaps the most surprising characteristic of these planets is that some of them (including 15 Pegasi b) have been found which have large mass ($\sim M_J$) with orbits very close to their star (~ 0.05 AU). This is surprising because the environment close to the star is far too hot for giant planet formation to occur[3].

Some years ago, it was suggested[4, 5] that the close-in extrasolar planets might be composed not of ordinary matter, but primarily of mirror matter[6]. If this were the case, then the close-in orbits of the planets would not pose any problem. A significant ordinary matter subcomponent ($\sim 10^{-3} M_J$) would necessarily occur – being accreted from the stellar wind of the host star[5]. The ordinary matter subcomponent will make the mirror planet opaque to ordinary radiation with an effective radius, R_p. The ordinary matter subcomponent would be very hot and (relatively) low in density. This means that the ideal gas law could be used to relate the pressure to the density and temperature and from the condition of hydrostatic equilibrium a simple relation could be derived for R_p[5]:

$$R_p \propto \sqrt{\frac{T_s}{M_p}} \tag{1}$$

where T_s is the surface temperature of the planet and M_p is the mass of the planet. This was only a rough prediction (especially the dependence on T_s) but a prediction nevertheless. Heuristically it is very easy to understand: increasing the mass M_p increases the force of gravity which causes the gas of ordinary matter to become more tightly bound to the mirror planet (thereby decreasing the effective size, R_p), while increasing the temperature of the gas increases the volume that the gas occupies (thereby increasing R_p). Of these two effects we expect that the dependence on M_p should be the more robust prediction. Because the size of ordinary gas giant planets (i.e. planets made mostly of ordinary matter) depends quite weakly on their mass the dependence on M_p, which is significant according to Eq.(1), should allow a decisive test of the mirror planet hypothesis.

Although radial velocity surveys have been very successful in finding planetary candidates, they do not give the mass of the planet, only $M_p \sin i$, and do not provide information about the planet's size, R_p. This information can be obtained if transiting systems are found. In this case $\sin i \simeq 1$ (which means that the mass of the planet can be established from the radial velocity measurements), and the depth of the transit can be used to estimate the planets size. The first transiting planet, HD209458b was discovered in 1999[7, 8, 9], with parameters $M_p = 0.69 \pm 0.05 M_J$ and $R_p = 1.43 \pm 0.05 R_J$[10]. The large size of this planet indicates that the interior is very hot, with some authors suggesting that some internal heating mechanism is required[11] while others argue that this is not necessary[12].

Following the discovery of the first transiting planet, HD209458b, intensive efforts have been underway to search for other transiting extrasolar planets. The OGLE survey (Optical Gravitational Lensing Experiment) announced the detection

of more than 100 short-period transiting objects[13]. These observations were followed up with radial velocity measurments leading to the recent discovery of three new transiting planets: OGLE-TR-56b[14], OGLE-TR-113b[15, 16] and OGLE-TR-132b[15]. It will be interesting to see how well the rough prediction, Eq.(1), agrees with this new data.

The effective surface temperature of the planet, T_s, can be related to that of the star via:

$$T_s = \left(\frac{1-a}{4}\right)^{1/4} \left(\frac{R_{star}}{D}\right)^{1/2} \; T_{eff}^{star} \tag{2}$$

where a is the albedo, R_{star} is the radius of the star and D is the (mean) orbital distance of the planet. The parameters $D,\ R_{star},\ T_{eff}^{star}$ for the systems with transiting planets are given in table 1.

Transiting planet	D $[AU]$	R_{star} $[R_\odot]$	T_{eff}^{star}
HD209458b	0.045[7]	1.20 ± 0.02[10]	6000 ± 50 K[9]
OGLE-TR-56b	0.0225[14]	1.10 ± 0.10[17]	5900 ± 80 K [17]
OGLE-TR-113b	0.0228[15]	0.765 ± 0.025[15]	4752 ± 130 K[15]
OGLE-TR-132b	0.0306[15]	$1.41^{+0.49}_{-0.10}$[15]	6411 ± 179 K[15]

Table 1: The stellar radius (R_{star}), temperature (T_{eff}^{star}) and the mean orbital radius (D) for the four known transiting systems.

Using, Eq.(2) and the parameters from the above table, we can estimate the effective temperatures for the four transiting planets (we assume an albedo of $a = 0.3$[2]). This information, together with the measured mass and radius we give in table 2 below:

Transiting planet	R_p $[R_J]$	M_p $[M_J]$	T_s
HD209458b	1.43 ± 0.05[10]	0.69 ± 0.05 [9]	1370 K
OGLE-TR-56b	1.23 ± 0.16[14]	1.45 ± 0.23[14]	1820 K
OGLE-TR-113b	1.08 ± 0.07[15]	1.35 ± 0.22[15]	1210 K
OGLE-TR-132b	$1.15^{+0.80}_{-0.13}$[15]	1.01 ± 0.31[15]	1920 K

Table 2: The planet radius (R_p), mass (M_p) and effective surface temperature (T_s) for the four known transiting planets. For the planet OGLE-TR-113b, we take the values given in Ref.[15] (similar results were independently obtained in Ref.[16]).

In figure 1 we plot the values of R_p versus $\sqrt{T_s/M_p}$ for the three most accurately measured planets, HD209458b, OGLE-TR-56b and OGLE-TR-113b. The solid line

[2]Note the dependence of R_p on the albedo suggested by Eq.(1) is very weak $[\propto (1-a)^{1/8}]$ and for this reason possible uncertainty in albedo does not significantly affect the prediction for R_p.

is the prediction, Eq.(1), where we have used HD209458b to fix the proportionality constant. Clearly, the observations agree remarkably well with the rough prediction, Eq.(1). This appears to be non-trivial: in the case of ordinary matter planets, increasing the mass does not significantly affect the radius, and does not generally lead to a decreasing radius (for example, Jupiter is three times heavier than Saturn, but is 15% *larger*).

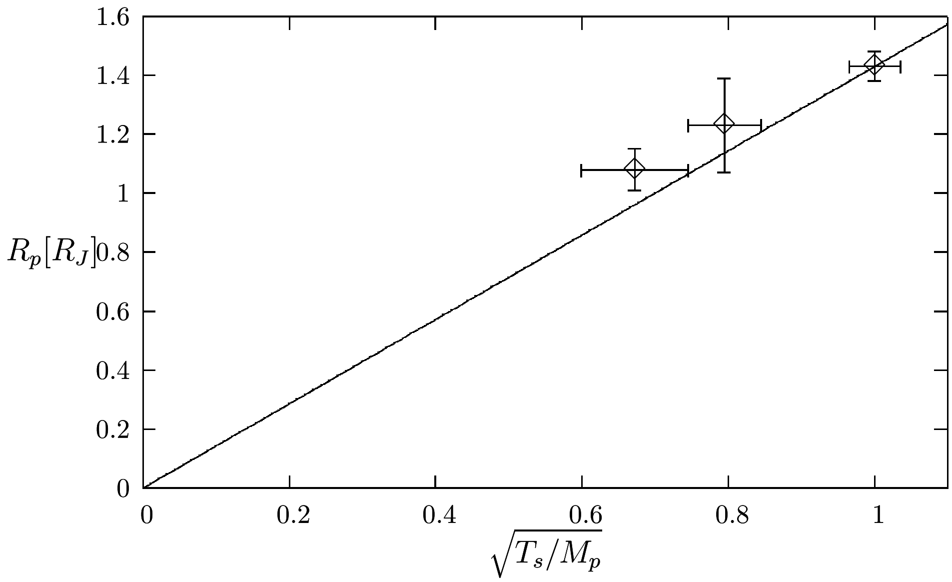

Figure 1: The measured effective size, R_p, of the transiting planets HD209458b, OGLE-TR-56b and OGLE-TR-113b versus $\sqrt{T_s/M_p}$ (in units where $\sqrt{T_s/M_p} = 1$ for HD209458b). The straightline is the prediction, Eq.(1), which assumes that the planets are composed predominately of mirror matter.

In conclusion, we have compared the rough prediction, Eq.(1), with the recently discovered close-in transiting planets OGLE-TR-56b and OLGE-TR-113b. This prediction is found to be in agreement with the observations which seems to favour the mirror matter interpretation of the close-in extrasolar planets. However, it is certainly possible that the apparent agreement with the rough predicition, Eq.(1) is coincidental – so more data would be welcome. Especially decisive would be the discovery of a much heavier transiting planet, $M_p \gtrsim 2M_J$, which should have a radius less than R_J if it is a mirror world.

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